Published online March 29, 2006

Tillage Effects on Nitrogen Dynamics and Grass Seed Crop Production in Western Oregon, USA

M. A. Nelson, S. M. Griffith,* and J. J. Steiner

ABSTRACT

Understanding N soil fertility in grass seed crops will lead to improved fertilizer practices and preserve water quality in Willamette Valley, Oregon. This study determined the effects of conventional tillage (CT) and no tillage (NT) on N dynamics and grass seed crop growth and seed yield on moderately well-drained (MWD) and a well-drained (WD) soils either in tall fescue (*Festuca arundinacea* Schreb.) or fine fescue (*F. rubra* L.) production. Temporal changes in soil N, N mineralization and immobilization, crop N uptake and biomass accumulation, and microbial biomass C (MBC) were determined. Net N mineralization was determined using the in situ buried bag method and MBC by fumigation extraction. Tillage treatment had no effect on fine fescue and tall fescue seed yield during the 3 yr of production. Soil MBC, under NT, was 20 to 30% higher ($P = 0.05$), regardless of soil drainage class or time of year, compared to the CT soil. Soils at the WD site had twice the amount of MBC compared to MWD. Crop N uptake was lowest in the fall and highest when soil N was elevated in the spring. Tillage enhanced annual total net N mineralization at the better-drained site (WD) resulting in more potential soil NO_3 to be leached the following winter high precipitation months when the crop's demand for N is low. This was especially true for fallow years when an actively growing crop was lacking. Net N mineralization was little affected by tillage in the more poorly drained soil.

In western Oregon, grass seed crops grow and produce seed from September to June at a time when 97% of the 1109 mm of annual precipitation is received. This precipitation regime facilitates soil NO_3 flushes to shallow and surface waters because adequate plant and soil microbe N sinks are weak (Griffith et al., 1997c). During the winter months NO_3 flushing is greatest (Griffith et al., 1997c). Research data indicates that the source of much of the NO_3 flushed to shallow ground and surface water was from soil mineralization processes (Griffith et al., 1997c), whereas, directly applied fertilizer N inputs to this flushing phenomenon appear minimal (S.M. Griffith, unpublished data, 2002). Thus, with regard to reducing N loss from grass seed fields and minimizing potential effects of off-site NO_3 movement on water quality, a better understanding of mineralization processes in western Oregon is imperative because information is currently lacking. It is especially important to understand how tillage management, which can greatly influence soil NO_3 levels, affects soil N mineralization (N source) and N use by the crop (N sink).

Soil ammonium, directly from applied fertilizer or soil N mineralization, readily binds to soil making these ions relatively immobile. Dispersion of NH_4 to waterways, through processes of soil erosion or after being nitrified to NO_3, can create water quality problems for fish and aquatic wildlife at certain concentrations, temperature, and dissolved oxygen conditions. Nitrification processes transform NH_4 to NO_2 and NO_3. These soil processes can occur rapidly by soil microbes with adequate soil moisture and temperature under oxidizing conditions. Nitrite and NO_3 are relatively mobile, and when not absorbed by plants or microorganisms, can easily move to ground and surface water and adversely affect aquatic wildlife at certain concentrations (Mueller and Helsel, 1996).

Soil drainage, tillage, and crop residue have key influences on mineralization processes, thus it is important to understand how mineralized N are affected by grass seed crops under both conventional and conservation tillage and high residue management conditions on different classes of soil drainage. Currently, there is a trend in western Oregon grass seed production systems to flail-chop postharvest residue and not incorporate it into the soil, and to adopt NT practices. The large amount of soil disturbance of CT accelerates C loss and promotes N mineralization (Stewart and Bettany, 1982). Previous work has demonstrated that NT management increases microbial biomass in agricultural soils (Doran, 1987; Gravatstein et al., 1987; Carter, 1991), as well as the closely related content of active N (Belvins et al., 1977; Lamb et al., 1985; Havlin et al., 1990; McCarty et al., 1995). Compared with NT, CT systems decrease potentially mineralized C and N (Woods and Schuman, 1988) and the soil's ability to immobilize and thus conserve mineral N (Follett and Schimel, 1989). Greater potentially mineralizable N under NT compared to CT, in the upper 7.5 cm of soil, has been associated with a larger microbial biomass (Doran, 1980). A common observation is that the N supplying potential of the soil increases after NT practices have been utilized for a few growing seasons (Franzluebbers et al., 1994), as does the closely related content of active N (McCarty et al., 1995).

Information is lacking in western Oregon about factors that regulate soil N mineralization, including the effects of crop production practices such as tillage. In situ soil N mineralization is rarely measured in agricultural field studies and never in western Oregon. Estimates of N mineralization are commonly based on laboratory incubations conducted under controlled environments and have little relevance to temporal changes in field N mineralization and how it relates to fluctuating crop N sinks. In contrast, methods for measuring soil N mineralization in situ have been routinely used in forest and

M.A. Nelson, S.M. Griffith, and J.J. Steiner, USDA-ARS, National Forage Seed Production Research Center, Corvallis, OR 97331. Received 26 July 2005. *Corresponding author (griffits@onid.orst.edu).

Published in Soil Sci. Soc. Am. J. 70:825–831 (2006).
Soil & Water Management & Conservation
doi:10.2136/sssaj2005.0248

677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: CT, conventional tillage; GDD, growing degree days; MBC, microbial biomass C; MWD, moderately well-drained; NT, no tillage; SOM, soil organic matter; WD, well-drained.

natural ecosystem studies (Binkley and Hart, 1989; Eno 1960) and can be of great value when used in agricultural systems.

The objective of this study was to determine the effects of CT and NT on crop production in relation to soil mineral-N availability, net N mineralization, and soil microbial biomass C over three cycles of tall fescue or fine fescue seed production. We hypothesized that: (i) during the first year of perennial grass seed crop establishment, using NT, that in situ net N mineralization would be lower compared to rates found for CT soil; (ii) MBC would be greater under NT management; and (iii) following the crop establishment year, perennial grass seed crop soils would return to a more N conserving system, reducing potential mineralized-N losses to the environment.

MATERIALS AND METHODS

Research plots were located in the Willamette Valley of western Oregon (USA), at two locations contrasting in soil drainage classification and grass species grown (see Nelson, 2003). One site was located on a private farm located in the Silverton Hills region of eastern Marion County (44°56′ N, 122°45′ W); herein referred to as the WD site. The second site was located on the valley floor at the Oregon State University Hyslop Research Farm in Benton County, Oregon (44°38′ N, 123°12′ W); herein referred to as the MWD site with slow permeability and a seasonally high water table.

The WD Marion County soil was representative of soils in the north Willamette Valley foothills compared to the MWD site in Benton County that was typical of some of the southern valley soils. At both locations soil water flow was by percolation. At the Marion site the soil water permeability was moderately slow. At the MWD site soil water permeability was moderate in the upper part of the subsoil and slow in the lower part. These soils were chosen for the study for their extensive presence in the area and contrasting physical and chemical characteristics, which are thought to influence N mineralization processes (Table 1).

The Willamette Valley has a Pacific Northwest marine climate, with hot, dry summers and cool, wet winters. Meteorological data were collected by the Oregon Climatic Service (http://www.ocs.orst.edu; verified 17 Dec. 2005) at Hyslop Farm for the Benton County and at the Silverton location for the Marion County WD site. Accumulated growing degree days (GDD) were calculated by the formula $\{[(T_{\max} + T_{\min})/2] - T_{\text{base}}\}$, where T represents air temperature and T_{base} was 0°C (Griffith et al., 1997a).

Sites were established in 1992 by the USDA-ARS National Forage Seed Production Research Center as part of a long-term integrated agricultural systems study (Gohlke et al., 1999; Steiner et al., 2006). The study contrasted tillage establishment, crop rotation, and residue management practices. The treatments imposed were direct seeding versus tillage and a subtreatment of seed year. All treatments were replicated with four blocks measuring 560 m^2 each. In the spring of 1999, plots were planted with fine fescue (cv. Bridgeport) (WD site) and tall fescue (cv. Hounddog) (MWD site). First, second, and third year stands were included in this study.

Crop management at the WD site consisted of a fallow (2000–2001) and first-year (1999–2000), second-year (2000–2001), and third-year (1999–2000) fine fescue seed crops on soil in continuous 3-yr rotations since 1992. Since our study began after the 1998 to 1999 fallow season, which our first and second production years followed, data presented here for the fallow season were taken in the next time series of the USDA-ARS long-term cropping system research study that began in the fall of 2000 (Gohlke et al., 1999; Steiner et al., 2006). The CT plots were last tilled September 1998 and planted April 1999 and NT plots were last tilled September 1992 and planted April 1999. The third-year CT plots were last tilled May 1995 and planted late April 1997. Since the study began after the first fallow season of 1998 to 1999, data for the fallow season were taken in the next time series of the USDA-ARS cropping system long-term research study which began fall 2000. All plots were fertilized each spring with 134 kg N ha^{-1}, with urea 46–0–0–0.

Crop management at the MWD site consisted of a fallow (2000–2001) and first-year (1999–2000), second-year (2000–2001), and third-year (2000–2001) tall fescue seed crops on soil in continuous 3-yr rotations since 1992. Since our study began after the 1998 to 1999 fallow season, which our first and second production years followed, data presented here for the fallow season were taken in the next time series of the USDA-ARS long-term cropping system research study that began in the fall of 2000 (Gohlke et al., 1999; Steiner et al., 2006). The CT plots were last tilled September 1998 and planted March 1999. The NT plots were last tilled October 1994 and planted March 1999. All plots were fertilized in the spring each year with 134 kg N ha^{-1}, using urea (46–0–0–0).

The in situ buried bag method (Eno, 1960; Binkley and Hart, 1989) was used to quantify net N mineralization using 24 incubations, September 1999 to June 2001, with an average incubation period of 26 d. Three pairs of intact soil cores measuring 50 mm in diameter by 150 mm in length were taken within each plot. One of the core-pairs (N_{final}) was sealed within a self-sealable polyethylene bag (approximately 27 by 28 cm; 1.75-mil thickness) and replaced in its original position in the soil. The bag was covered with loose soil and litter to reduce exposure. N_{final} was collected approximately 26 d later. The other core-pair (N_{initial}) was transported to the laboratory sealed in a sealable polyethylene bag for analyses of baseline soil properties. Soil water content was estimated by oven drying at 105°C for 24 h.

Three separate subsamples from the main sample core were extracted with 100 mL of 0.5 M K_2SO_4, shaken for 30 min on a rotary shaker at 350 rpm and filtered through a Whatman no. 1 filter. The filtrate was then analyzed for NO_3–N and NH_4–N using a Lachat Quick Chem 4200 analyzer (Milwaukee, WI). An additional set of three soil subsamples were taken for determination of soil moisture by gravimetric methods and determination of soil organic matter (SOM) by combustion.

Soil microbial biomass C (MBC) was determined by $CHCl_3$ fumigation extraction method (Horwath and Paul, 1994). This method measures total organic C (TOC) in extracts of $CHCl_3$–

Table 1. Soil classification and physicochemical characteristics of a moderately well-drained (MWD) and well-drained (WD) sites in the Willamette Valley of western Oregon.

Site	Soil type	Classification	Depth	pH	Organic matter	Carbon	Clay
			cm		%		
MWD	Nekia–Jory	fine, mixed, active, mesic Xeric Palehumult	15	5.6	7	4.0	24.7
WD	Woodburn	fine-silty, mixed, superactive, mesic Aquultic Argixeroll	15	5.2	4	1.3	16.2

fumigated and nonfumigated soils. Six subsamples from each soil core were used for this analysis. Analyses were performed using a Tekmar-Dorhmann Phoenix 8000 UV-Persulfate TOC analyzer (Mason, OH).

Aboveground crop biomass was collected from three 30-cm^2 randomly selected areas in each replicated treatment on 30 Jan., 29 Feb., 30 Mar., 27 Apr., 25 May, 26 June, and 30 Oct. 2000 and 13 Feb., 13 Mar., 13 Apr., 29 May, and 25 June 2001. Biomass was forced-air dried at 70°C for 24 h and then weighed. Plant material was ground using a Tecator Cyclotec 1093 sample mill (Eden Prairie, MN) and analyzed for total N using a PerkinElmer 2400 Series II CHNS/O analyzer (Shelton, CT). Seed yield was determined following pollination during late June. Plots were swathed into windrows. Seed yield from each plot was measured using a Bent Yield Cart and adjusted for clean seed yield.

Calculation of Nitrogen Mineralization and Nitrification

The rate of net N mineralized was calculated by:

$$\text{Net N mineralization} = \frac{\left[\left(\frac{NH_4-N}{\text{kg}_{\text{final}}}\right) + \left(\frac{NO_3-N}{\text{kg}_{\text{final}}}\right)\right] - \left[\left(\frac{NH_4-N}{\text{kg}_{\text{initial}}}\right) + \left(\frac{NO_3-N}{\text{kg}_{\text{initial}}}\right)\right]}{\text{time}} \quad [1]$$

$$\text{Net N nitrification} = \frac{\left[\left(\frac{NO_3-N}{\text{kg}_{\text{final}}}\right) - \left(\frac{NO_3-N}{\text{kg}_{\text{initial}}}\right)\right]}{\text{time}} \quad [2]$$

Calculation of Microbial Biomass Carbon

Microbial biomass C in the soil was calculated from the amounts of CO_2 C extracted from the fumigated and nonfumigated soil samples:

$$\text{MBC} = (\text{F} - \text{NF})/\text{k}$$

where:

F = extractable C from fumigated samples;
NF = extractable C from nonfumigated samples; and
k factor = 0.41 (Horwath and Paul, 1994)

Statistical Analysis

Data were analyzed using an ANOVA to determine if there were significant differences between calendar year and, if no differences, data were pooled and an ANOVA was used to determine if there were significant differences between the two treatments for each sample date. Main effects were direct tillage (NT and CT) and site. The subtreatments were plant year (fallow, first year, and second year). All values were expressed as the mean of four replications ± one standard error and significance determined at the $P = 0.05$ level.

RESULTS AND DISCUSSION

Precipitation

Crop season 2000–2001 was substantially drier than the 1999–2000 season. During 2000–2001, the annual precipitation was 563 mm (48% below the 30-yr mean) at the MWD site and 756 mm (36% below the 30-yr mean) at WD site. In contrast, the total precipitation for the 1999–2000 crop season was near normal (30-yr average); 1068 mm at MWD and 1135 mm at WD. For both crop years at the MWD site, 91% of the annual precipitation fell from October 1 to June 30 (2-yr average) and 97% at the WD site during the same period. During the 2000–2001 season, MWD site precipitation totaled less than the 30-yr average by 47% in the fall, 65% in the winter, and 24% in the spring. For the 2000–2001 season, WD site precipitation totaled less than the 30-yr average by 31% in the fall, 58% in the winter, and 11% in the spring. In both crop years, summers received virtually no measurable precipitation.

Soil Water

Soil water (w/w) at the WD site was significantly higher ($P = 0.05$) by 4% compared to the MWD site (Table 2; Nelson, 2003) and was probably due to slightly greater precipitation and, in part, to the higher SOM in the WD soils. The WD site had 3.9% higher ($P = 0.05$) SOM than soils at the MWD site (Table 1; Nelson, 2003). Soil organic matter can hold up to 20 times its mass in water (Stevenson, 1994). Another factor would be the percentage of clay content; the higher soil clay content the higher the soil's capacity to retain water. Soil at the WD site had 18% more clay than the MWD site (Table 1). Tillage did affect percentage of soil water; tilled plots had significantly ($P = 0.05$) higher soil water than the direct seeded plots (Table 2).

Crop Development

Temporal changes in crop phenology, with respect to GDD, were documented to match soil and plant biotic factors (e.g., net N mineralization and plant N uptake) with crop development. It was found that the stages of plant development in tall fescue and fine fescue, during both study years, coincided well with ranges of accumulated GDD, despite differences in total precipitation between years. In combining each year's data we report that the stage of plant development in tall fescue corresponded with accumulated GDD as follows: two- to three-leaf, 200 GDD (early February); three- to four-leaf, 300 to 400 GDD (late February to mid-March); four-leaf fully emerged, 500 GDD (late March); boot emergence, 700 to 850 GDD (late April); anthesis 1150 to 1200 GDD (late May); and seed harvest, 1550 to 1700 GDD (late June). The stage of plant development in fine fescue corresponded with accumulated GDD as follows: two- to three-leaf, 150 to 250 GDD (early February); four-leaf, 300 to 450 GDD (early to mid-March); boot emergence, 600 to 700 GDD (mid April); anthesis 980 GDD (late May); and seed harvest, 1871 GDD (early July) for 2000 and 1474 GDD (mid-June) for 2001.

No till and CT had no affect ($P = 0.05$) on seed yield in tall fescue and fine fescue for stand years one and two (Table 3). Third-year seed yields were comparable to first year yields in both species. In the drier year (2000–2001), fine fescue seed harvest was much earlier with respect to GDD and calendar date. These data substantiate previous findings of Steiner et al. (2006).

Table 2. Statistical summary of effects of site, tillage and plant year on soil net N mineralization, nitrification, NH_4^+–N, NO_3–N, soil water content, microbial biomass carbon, and N fertilizer input for moderately well-drained (Benton site) and a well-drained (Marion site) soils located in Willamette Valley, Oregon.†

	Net N mineralization	Soils nitrification	NH_4^+–N	NO_3–N	Soil water	Microbial biomass C
Main effect						
Site	ns‡	*	*	ns	*	*
Tillage	*	*	ns	***	*	**
Plant year	**	***	**	***	ns	ns
Date	**	***	***	***	***	ns
Two-way interactions						
Site × tillage	ns	ns	ns	*	ns	ns
Site × plant year	ns	ns	*	ns	*	ns
Site × date	**	***	**	**	***	*
Tillage × date	*	ns	ns	*	ns	ns
Plant year × date	**	***	**	**	**	ns
Tillage × plant year	ns	ns	ns	ns	**	ns
Three-way interactions						
Site × tillage × date	ns	ns	ns	ns	**	**
Site × tillage × plant year	*	*	ns	**	ns	ns
Site × plant year × date	**	*	**	**	**	ns
Tillage × plant year × date	ns	ns	ns	**	**	ns
Four-way interactions						
Site × tillage × plant year × date	ns	ns	ns	*	ns	ns

* Significance $P < 0.05$.
** Significance $P < 0.01$.
*** Significance $P < 0.001$.
† Fine fescue (*Festuca rubra* L.) and tall fescue (*F. arundinaceum* Schreb.) were grown for seed. The rate of N fertilizer applied for all treatments and sites was 134 kg N ha^{-1} yr^{-1} applied as a split application in the spring.
‡ ns, not significant.

Crop Biomass and Nitrogen Accumulation

During the 1999–2000 and 2000–2001 study years, at both locations, for seed years one and two, CT had no effect on fine fescue and tall fescue aboveground biomass and N accumulation, compared to the NT treatment (Table 4; Nelson, 2003). Tall fescue aboveground biomass accumulated about 300 kg N ha^{-1} yr^{-1}, while fine fescue aboveground biomass accumulated approximately 200 kg N ha^{-1} yr^{-1}. Shoot N uptake and biomass accumulation occurred relatively concurrently in both species and was initiated between 400 and 530 GDD (15 March 15–1 April) each year and coincided with spring fertilizer-N application and the rise in soil N mineralization.

Tall fescue had greater N uptake than fine fescue but the WD site (with fine fescue) had greater N mineralization than the MWD site (with tall fescue). The greater excess N at the WD site resulted from lower crop N uptake and greater soil N mineralization (Table 3). There could be greater potential for N loss to ground and surface waters at the WD site if N fertilizer was mismanaged. During the fallow year, at the WD site, both NT and CT had 211 and 284 kg N ha^{-1} of residual N, respectively, and the MWD site had 176 and 196 kg N ha^{-1},

Table 3. Statistical summary of effects of site, tillage and plant year on total plant N accumulation, seed yield, total net N mineralization, and N fertilizer input for moderately well-drained (Benton site) and a well-drained (Marion site) soils located in Willamette Valley, Oregon.†

	Plant and soil			
	Total plant N accumulation	Seed yield	Total net N mineralization	Total N remaining
Main effect				
Site	*	ns‡	*	*
Tillage	ns	ns	ns	ns
Plant year	**	**	ns	**

* Significance $P < 0.05$.
** Significance $P < 0.01$.
*** Significance $P < 0.001$.
† Fine fescue (*Festuca rubra* L.) and tall fescue (*F. arundinaceum* Schreb.) were grown for seed. The rate of N fertilizer applied for all treatments and sites was 134 kg N ha^{-1} yr^{-1} applied as a split application in the spring. For both species, root N was determine to be about 11% of the total N accumulated.
‡ ns, not significant.

Table 4. Statistical summary of effects of site, tillage and plant year on total plant biomass (kg ha^{-1}), C (kg ha^{-1}), and N (kg ha^{-1}) and N fertilizer input for moderately well-drained (Benton site) and a well-drained (Marion site) soils located in Willamette Valley, Oregon.†

	Plants		
	Biomass	C	N
Main effect			
Site	***	***	***
Tillage	ns‡	ns	ns
Plant year	***	***	***
Date	***	***	***
Two-way interactions			
Site × tillage	ns	ns	ns
Site × plant year	ns	ns	ns
Site × date	***	***	***
Tillage × date	ns	ns	ns
Plant year × date	ns	ns	ns
Tillage × plant year	***	***	***
Three-way interactions			
Site × tillage × date	**	**	**
Site × tillage × plant year	**	**	**
Site × plant year × date	ns	ns	ns
Tillage × plant year × date	ns	ns	ns

* Significance $P < 0.05$.
** Significance $P < 0.01$.
*** Significance $P < 0.001$.
† Fine fescue (*Festuca rubra* L.) and tall fescue (*F. arundinaceum* Schreb.) were grown for seed. The rate of N fertilizer applied for all treatments and sites was 134 kg N ha^{-1} yr^{-1} applied as a split application in the spring.
‡ ns, not significant.

respectively. This residual soil N, predominately NO_3, could potentially be lost in the system during the fall and winter high rainfall months. During the normal rainfall year, the WD site had an excess of 167 kg N ha^{-1} and during the dry year an excess of 14 kg N ha^{-1}, the MWD site was −64 kg N ha^{-1} and −26 kg N ha^{-1}; this was determined by adding the net annual mineralization and fertilizer N and then subtracting plant aboveground biomass N before harvest. Aside from N leaching, these estimates do not take into account N losses from denitrification (Horwath et al., 1998) or urea vitalization. Fine fescue and tall fescue crop N uptake efficiencies were lowest during the fall season when crop N uptake was least. In contrast, plant N uptake efficiency during the drier spring months was high, which would reduce potential soil N loss. This is further evidence that fall fertilization would intensify N loss through the winter N flushing period.

Microbial Biomass Carbon

Across tillage treatments, soil MBC was two times higher ($P = 0.05$) at the WD site than the MWD site (Table 2; Nelson, 2003). Microbial biomass C ranged from 100 to 200 mg C kg^{-1} soil at the Benton site and 250 to 370 mg C kg^{-1} soil at the Marion site (Nelson, 2003). This could be explained by differences in percent organic matter and total C (Table 1), as well as differences in soil water holding capacity and aeration. The WD site had twice as much percentage of organic matter and total C, and had higher soil water content, on average, than the MWD site. Moore et al. (2000) found that systems with higher organic matter inputs, and more readily available organic matter compounds, tend to have higher microbial biomass contents.

At the MWD site, soil MBC declined immediately following tillage compared to the NT treatment. At the MWD site, MBC also declined through the season regardless of tillage treatment. This trend continued through the first seed production year. Similarly, at the WD site MBC content declined after tillage but remained at a constant level through the fallow season. The NT/CT MBC ratios remained fairly constant through the season, with the exception of the WD site where MBC content rose at season's end in the first seed production year following NT. By the second and third seed production year, soil MBC level at both sites fluctuated less throughout the season as if it was reaching equilibrium. This was particularly striking at the WD site. These data corroborate reports of other investigators showing that MBC increases under direct seeding (Doran, 1980; Carter and Rennie, 1982; Franzluebbers et al., 1994). The combination of the residue management and NT cultivation used in this study favored a nutrient-rich environment for soil microorganisms to survive and flourish and would account for the observations reported here. Although there is little evidence that enhanced MBC levels in the soil relate to crop productivity, MBC is an overall indicator of soil microbiological activity of the soil environment and may provide information related to soil nutrient processing and crop nutrient acquisition.

Soil Nitrogen

Unlike some poorly drained Willamette Valley, Oregon soils, where NH_4 was the dominant N form for much of the winter (Griffith et al., 1997b), NO_3 was the dominant N form at the fine fescue (WD) and tall fescue sites (MWD) sites. Common among all seed crop production years and study sites, fall soil NO_3 levels declined appreciably from November to January, the months of highest annual precipitation. Early fall soil NO_3 levels ranged from approximately 5 to 50 kg N ha^{-1}. This fall–winter soil NO_3 flush was facilitated by high rainfall at a time when crop biomass was a weak N sink due to cooler temperatures and shorter days slowing crop growth. During the winter months of January through most of March, soil NO_3 concentrations reached their lowest levels, maintaining soil NO_3 concentrations of 1 to 10 kg N ha^{-1}. Soil NO_3 began to increase in April and May and was attributed to both urea fertilizer application and the stimulation of microbial mineralization of soil organic N. Interestingly, at both sites soil NH_4 levels were lowest in the drier year probably resulting from appreciable reductions in mineralization and a more favorable soil environment for nitrification due to a tighter coupling between mineralization and nitrification processes.

Net Nitrogen Mineralization

The WD site had higher rates of net nitrification in the spring compared to the MWD site, where net nitrification rates were greatest in the fall (Nelson, 2003). Annual net N mineralization ranged from 35 to 83 kg N ha^{-1} yr^{-1} (average 56.7 kg N ha^{-1} yr^{-1}) at the Benton site and at the Marion site from 32 to 164 kg N ha^{-1} yr^{-1} (average 91 kg N ha^{-1} yr^{-1}) for NT and 89 to 192 kg N ha^{-1} yr^{-1} (average 155 kg N ha^{-1} yr^{-1}) for CT. These enhanced rates of N processing where significantly ($P = 0.05$) more pronounced in the normal rainfall year. Net nitrification was significantly enhanced ($P = 0.05$) by CT (Table 2). The total annual net nitrification was significantly ($P = 0.05$) greater in tilled soil (Table 3).

Net N mineralization rate varied with soil drainage class. Tilled WD soil resulted in a higher net mineralization rate in the fall following tillage and sowing the previous fall and spring, respectively. Winter 2000 WD first-year CT net mineralization rates were lower than WD NT rates. In contrast, MWD soil resulted in little difference in the rate of net N mineralization among tillage treatments and crop year. Our findings confirm findings of Rice et al. (1987) which showed similar results in contrasting poorly drained and well-drained soils as affected by CT and NT management using a laboratory in vitro intact core mineralization procedure.

At the MWD and WD sites, during the first seed year, net N mineralization rates in the spring, before urea fertilizer application, were greater under NT compared to the CT treatment. Other field studies have shown that spring net N mineralization rates were similar or higher in direct drilled or reduced tilled soils, compared with cultivated soils (Kohn and Cuthberton, 1966; Reeves and Ellington 1974; Stein et al., 1987).

CONCLUSIONS

The study was the first to show that CT directly impacted soil abiotic and biotic factors in western Oregon grass seed productions systems, to the extent of reducing N retention, but tillage method did not affect fine fescue and tall fescue seed yield (Gohlke et al., 1999; Nelson, 2003; Steiner et al., 2006).

Tillage enhanced N mineralization resulting in more soil NO_3 residing in the fall and winter at a time when the crop N sink was lowest. Soil NO_3 surplus during this period was subject to major leaching by late fall and winter rainfall. This is especially true for fallow years when an actively growing cover crop was not present. Data here indicated that the magnitude of this response was enhanced in better drained soils. These findings do not support the practice of fall fertilization of western Oregon grass seed crops where the majority of the approximately 1100 mm of precipitation occurs in late fall and winter. Based on soil and plant N dynamics reported here we suggest that growers apply fertilizer N to their perennial grass seed crops in the spring around 400 to 550 GDD in one or split applications depending on the total amount to be applied. Phonologically this period of N application corresponds with the four-leaf stage of development around the time of shoot elongation. The lower recommended N fertilizer rates for fine fescue, 34 to 56 kg N ha^{-1}, compared to tall fescue, 101 to 151 kg N ha^{-1} (Young et al., 2002), seem reasonable considering that fine fescue seed crops are usually grown on well-drained soils in Willamette Valley, OR, which theoretically would be expected to provided greater amounts of mineralized N than the more poorly drained soils in which tall fescue is often grown. Growers should keep in mind that mineralized N inputs can vary annually with changes in weather, so the optimum N fertilizer rate might need to be adjusted depending on N mineralization inputs. Net N mineralization tests have been developed locally and are available to growers that would approximate N mineralization values for any given soil (Christensen et al., 2003). Data here also indicate that drier years reduce mineralized N inputs; therefore adjustments in N rate may be especially necessary during drier years. It was found that MBC was higher when tillage did not occur. This corroborates, in general, numerous reports of other investigators that MBC was increased under direct seeding (Doran, 1980; Carter and Rennie, 1982; Franzluebbers et al., 1994). Microorganisms take part in the degradation of organic compounds and nutrient cycling into elements that are assimilated by plants.

Data confirm previous findings that fine fescue and tall fescue seed yields were not affected by CT and planting operations, compared to no till direct seeding (Gohlke et al., 1999; Steiner et al., 2006).

Aside from the environmental impact of tillage on soil quality, another incentive for farmers to convert to direct seeding, over conventional crop establishment, would be the proven economic advantage and time saved during conventional field preparation (Gohlke et al., 1999; Steiner et al., 2006). More research is needed under western Oregon climatic conditions to understand N processes as influenced by tillage and soil drainage. Future studies could examine more sites of differing soil drainage class in contrasting climatic years.

ACKNOWLEDGMENTS

This research was partially supported by a grant from the Oregon Seed Council in cooperation with the Oregon Department of Agriculture. The authors thank Dawn Rostad, Donald Streeter, Bill Gavin, and Rick Caskey for their technical assistance.

REFERENCES

Belvins, R.L., G.W. Thomas, and P.L. Cornelius. 1977. Influence of no-tillage and nitrogen fertilization on certain soil properties after 5 years on continuous corn. Agron. J. 69:383–386.

Binkley, D., and S.C. Hart. 1989. The components of nitrogen availability assessments in forest soils. Adv. Soil Sci. 10:57–112.

Carter, M.R. 1991. The influence of tillage on the proportion of organic carbon and nitrogen in the microbial biomass of medium-textured soils in a humid climate. Biol. Fertil. Soils 11:135–139.

Carter, M.R., and D.A. Rennie. 1982. Changes in soil quality under zero tillage farming systems: Distribution of microbial biomass and mineralizable C and N potentials. Can. J. Soil Sci. 62:587–597.

Christensen, N.W., M.H. Qureshi, D.M. Baloch, and R.S. Karow. 2003. Assessing nitrogen mineralization in a moist xeric environment. p. 6–9. *In* W. Young III (ed.) Seed production research. Oregon State Univ. Ext. and USDA-ARS, Corvallis, OR.

Doran, J.W. 1980. Soil microbial and biochemical changes associated with reduced tillage. Soil Sci. Soc. Am. J. 44:765–771.

Doran, J.W. 1987. Microbial biomass and mineralizable nitrogen distributions in no tillage and plowed soils. Biol. Fertil. Soils 5:68–75.

Eno, C.H. 1960. Nitrate production in the field by incubating the soil in polyethylene bags. Soil Sci. Soc. Am. Proc. 24:277–279.

Follett, R.F., and D.S. Schimel. 1989. Effects of tillage practices on microbial biomass dynamics. Soil Sci. Soc. Am. J. 53:1091–1096.

Franzluebbers, A.J., F.M. Hons, and D.A. Zuberer. 1994. Long-term changes in soil carbon and nitrogen pools in wheat management systems. Soil Sci. Soc. Am. J. 58:1639–1645.

Gohlke, T., S.M. Griffith, and J.J. Steiner. 1999. Effects of crop rotation and no-till crop establishment on grass seed production systems in the Willamette Valley, Oregon. USDA, NRCS Technical Notes, Agron. Tech. Note No. 30, November 1999. USDA-NRCS, Portland, OR.

Gravatstein, D.M., D.F. Bezdicek, V.L. Cochran, L.F. Elliot, and J. Hammel. 1987. Long-term tillage and rotation effects on soil microbial biomass carbon and nitrogen. Biol. Fertil. Soils 5:265–276.

Griffith, S.M., S.C. Alderman, and D.J. Streeter. 1997a. Italian ryegrass and N source fertilization in western Oregon in two contrasting climatic years. I. Growth and seed yield. J. Plant Nutr. 20: 419–428.

Griffith, S.M., S.C. Alderman, and D.J. Streeter. 1997b. Italian ryegrass and N source fertilization in western Oregon in two contrasting climatic years. II. Plant N accumulation and soil N status. J. Plant Nutr. 20:429–439.

Griffith, S.M., J.S. Owen, W.R. Horwath, P.J. Wigington, Jr., J.E. Baham, and L.F. Elliott. 1997c. Nitrogen movement and water quality at a poorly-drained agricultural and riparian site in the Pacific Northwest. Soil Sci. Plant Nutr. (Tokyo) 43:1025–1030.

Havlin, J.L., D.E. Kissel, L.D. Maddux, M.M. Clausen, and J.H. Long. 1990. Crop rotation and tillage effects on soil carbon and nitrogen. Soil Sci. Soc. Am. J. 54:448–452.

Horwath, W.R., L.R. Elliot, J.J. Steiner, J.H. Hart, and S.M. Griffith. 1998. Denitrification in cultivated and noncultivated riparian area of grass cropping systems. J. Environ. Qual. 27:225–231.

Horwath, W.R., and E.A. Paul. 1994. Microbial biomass. P. 753–774. *In* R.W. Weaver et al. (ed.) Methods of soil analysis: Microbial and biochemical properties. SSSA Book Ser. 5. SSSA, Madison, WI.

Kohn, G.D., and E.G. Cuthberton. 1966. Fallowing and wheat production in southern New South Wales. Aust. J. Exp. Agric. Anim. Husb. 6:233–241.

Lamb, J.A., G.A. Peterson, and C.R. Fenster. 1985. Wheat fallow system's effect of a newly cultivated grassland soil's nitrogen budget. Soil Sci. Soc. Am. J. 49:352–356.
McCarty, G.W., J.J. Meisinger, and F.M. Jenniskens. 1995. Relationships between total-N, biomass-N and active-N in soils under different tillage and fertilizer treatments. Soil Biol. Biochem. 27: 1245–1250.
Moore, J.M., S. Klose, and M.A. Tabatabai. 2000. Soil microbial biomass carbon and nitrogen as affected by cropping sytems. Soil Biol. Biochem. 31:200–210.
Mueller, D.K., and D.R. Helsel. 1996. Nutrients in the nation's waters: Too much of a good thing? USGS circular 1136. U.S. Gov. Print. Office, Denver, CO.
Nelson, M.A. 2003. N processing in grass seed crops differing in soil drainage and disturbance in western Oregon, U.S.A. M.S. thesis. Oregon State Univ., Corvallis, OR.
Reeves, T.G., and A. Ellington. 1974. Direct drilling experiments with wheat. Aust. J. Exp. Agric. Anim. Husb. 14:237–240.
Rice, C.W., J.H. Grove, and M.S. Smith. 1987. Estimating soil net nitrogen mineralization as affected by tillage and soil drainage due to topographic position. Can. J. Soil Sci. 67:513–520.
Stein, J.A., A.R. Sageman, R.A. Fischer, and J.F. Angus. 1987. Soil nitrogen supply of wheat in relation to method of cultivation. Soil Tillage Res. 10:243–258.
Steiner, J.J., S.M. Griffith, G.W. Mueller-Warrant, G.W. Whittaker, G.M. Banowetz, and L.F. Elliott. 2006. Conservation practice impacts in western Oregon perennial grass seed systems. I: Direct seeding and maximal residue management. Agron. J. 98:177–186.
Stevenson, F.J. 1994. Humus chemistry. Genesis, composition, reactions. 2nd ed. John Wiley & Sons, New York.
Stewart, J.W.B., and J.R. Bettany. 1982. Dynamics of soil organic phosphorus and sulfur. p. 8–16. *In* Trans. Int. Congr. Soil Sci., 12th, New Delhi, India. 8–16 Feb. 1982. Vol. 6. Indian Soc. Soil Sci. Agric. Chem., New Delhi.
Woods, L.E., and G.E. Schuman. 1988. Cultivation and slope position effects on soil organic matter. Soil Sci. Soc. Am. J. 52:1371–1376.
Young, W.C., III, M.E. Mellbye, G.A. Gingrich, T.B. Silberstein, S.M. Griffith, T.G. Chastain, and J.M. Hart. 2002. Defining optimum nitrogen fertilization practices for perennial ryegrass and tall fescue seed production systems in the Willamette Valley. p. 1–6. *In* 1999 Seed Production Research at Oregon State University USDA-ARS Cooperating 114. Oregon State Univ., Corvallis, OR.